OAK RIDGE NATIONAL LABORATORY
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Light Water Reactor Sustainability Program:

Report on the Installation of the Integrated Welding Hot Cell at ORNL Building 7930

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Report on the Installation of the Integrated Welding Hot Cell at Oak Ridge National Laboratory Building 7930

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Executive Summary

In order to address the growing need for advanced weld repair technologies, specifically those that enable repair of highly irradiated materials for nuclear power plant life extension, development is underway of a hot cell welding R&D facility located at Oak Ridge National Laboratory (ORNL) that will enable researchers to identify, test, and validate the performance of the most promising technologies directly on irradiated specimens. The welding facility has been developed through a partnership between the U.S. Department of Energy (DOE) and the Electric Power Research Institute (EPRI) through their Light Water Reactor Sustainability (LWRS) and Long Term Operation (LTO) Programs, respectively. Following extensive weld process development and system design and construction, the primary components of the welding facility have now been successfully integrated into Building 7930 of the Radiochemical Engineering Development Center (REDC) at ORNL. The necessary safety protocols that will enable start-up of welding activities on irradiated materials have been identified, and the Safety Basis Supplement that includes these activities was submitted to DOE on June 30, 2016 for a review and approval process that is anticipated to occur over approximately the next four months. Further, the acceptable functionality of the integrated welding system was demonstrated recently with initial start-up testing of the Friction Stir Welding (FSW) system on unirradiated representative stainless steel materials. The system performed well, executing automated welding programs according to specifications. The successful installation of the integrated welding hot cell and demonstration of the baseline performance of the FSW system establishes the foundation for a state-of-the-art DOE facility for welding R&D for repair of irradiated materials and other related R&D on irradiated materials.

I. Introduction

Welding is widely used for repair, maintenance and upgrade of nuclear reactor components, including in-situ repair of components with evidence of cracking and stress-corrosion cracking. As a critical mitigation technology to extend the service life of nuclear power plants beyond 60 years, weld technology must be further developed to avoid or reduce the detrimental effect associated with the traditional welding fabrication practices, as well as enable repair of highly irradiated materials. As nuclear power plants age, the extent and level of radiation damage will increase along with the demand for welding repair of irradiated structural internals. A significant problem that complicates thermal, stress, and chemical corrosion effects, along with irradiation damage, is the build-up of helium gas in structural materials due to transmutation of alloy constituents, boron and nickel, through neutron capture. During weld repairs, entrapped helium bubbles can grow at grain boundaries, leading to heat affected zone cracking.

Because of these complex mechanisms, a welding R&D facility was conceived that would enable direct testing of advanced welding technologies, those with promise for mitigating the aforementioned issues, directly on highly irradiated materials. The design, engineering, and construction of this facility, which includes capabilities for FSW, Laser Beam Welding (LBW), cold filler metal deposition, have been cost-shared with EPRI through its LTO program. This milestone was directed toward the completion of the installation of the welding cubicle and supporting systems into Building 7930 of REDC at ORNL, the evaluation of the necessary safety protocols for operation of the facility, and the demonstration of functionality of the FSW system on unirradiated representative stainless steel materials.

II. Status

Installation and Final Adjustment of the Integrated Welding Hot Cell into ORNL Building 7930

Following a period of weld system development and testing at EPRI, the welding cubicle and supporting equipment were transported to ORNL. Installation of supporting equipment in Building 7930 of REDC began while the welding cubicle was subject to a leak test prior to installation in the hot cell, which normally operates at a pressure of -4 inch H_2O. Supporting equipment for the system includes the LBW power supplies and chillers and the FSW power cabinet, which were installed in the new 7930 Mezzanine area (*Figure 1-background*).

Figure 1: Lowering of Welding Cubicle into 7930 Cell C from Mezzanine, with LBW and FSW Supporting Equipment Visible in Background

After successfully passing the leak test, the welding cubicle itself was moved into Building 7930, lowered into Cell C, and installed on its custom stand (*Figure 1-foreground, Figure 2*). The control panels and related monitoring equipment were positioned in the 7930 control room. Power cables, control cables, shield gas lines, and cooling system lines were routed as necessary via pass-throughs connecting Cell C with the Mezzanine and control room.

Figure 2: Welding Cubicle Sitting on Stand after Being Lowered into 7930 Cell C

Facility Readiness Assessment

A Readiness Assessment (RA) Determination was completed, and it was determined that an RA is not required for the start-up of welding activities in Building 7930 Cell C. In particular, the addition of the welding cubicle and supporting equipment did not constitute a "major modification" to the facility as determined in the Safety Basis subject area, and the start of welding activities does not qualify as an initial start-up of a new Hazard Category 1 or 2 activity or operation. Of significant concern was the laser system utilized in LBW; contained within the welding cubicle is a Class 4 fiber laser welding system. As part of the laser safety program required for all Class 4 laser systems (per ANSI standard Z136.1 - American National Standard for Safe Use of Lasers), a hazard analysis must be conducted by a qualified laser safety officer (LSO) to determine the potential for dangerous human exposure to laser radiation during emission and operation. After the laser hazard analysis however, it was found that, even by conservative calculations, the system as a whole could be considered a Class 1 laser system, given the protective housing supplied by the welding cubicle and the laser safety window of the cubicle.

The Safety Basis Supplement covering activities associated with welding irradiated materials at Building 7930 was submitted to DOE on June 30, 2016 for an approximate four month review and approval process.

Demonstration of Acceptable Functionality of the Integrated Welding System with Friction Stir Welding

Critical to acceptable FSW weld repair performance on irradiated materials will be control of the FSW tooling with respect to tool-workpiece engagement, rotational speed, travel speed, and proper execution of automated commands in pre-programmed weld routines. A specialized FSW system was designed and constructed for weld repair R&D activities in the hot cell cubicle, some specific characteristics of which include position, or displacement, controlled welding based on absolute positioning and a programmable logic controller (PLC) system for executing automated weld routines. Acceptable performance includes proper functionality from the PLC control system for the following key aspects of welding operations:

- Move the specimen table to the pre-weld start position
- Purge shield gas
- Start rotation of the tool
- Raise the specimen table to plunge the tool into the stainless steel coupon
- Stop the plunge phase at the prescribed tool depth
- Traverse the specimen table at the selected welding speed to make a friction stir weld
- Stop at the prescribed end-point
- Lower the specimen table to retract the FSW tool
- Stop rotation of the tool and stop the flow of shield gas
- Return the specimen table to the starting traverse position

Adequate cooling system performance throughout for protecting the FSW head from overheating is also a requirement. The ability of the system to achieve these tasks was evaluated in the start-up cold testing of the FSW system on unirradiated representative stainless steel materials.

FSW system tests were carried out by executing a series of friction stir welds on unirradiated specimens, a standard configuration of which includes a run-on tab, weld coupon, and a run-off tab of 304 stainless steel. Figure 3 displays a friction stir weld being performed in the hot cell welding cubicle as part of the system functionality testing and demonstration. The purpose of the run-on and run-off tabs is to increase the overall weld length, increasing the segment of the process that is considered to be at steady-state, and thereby increasing the portion of the weld coupon that can subsequently be analyzed. When welding of irradiated specimens occurs, only the middle weld coupon will be irradiated, while the tabs will be unirradiated.

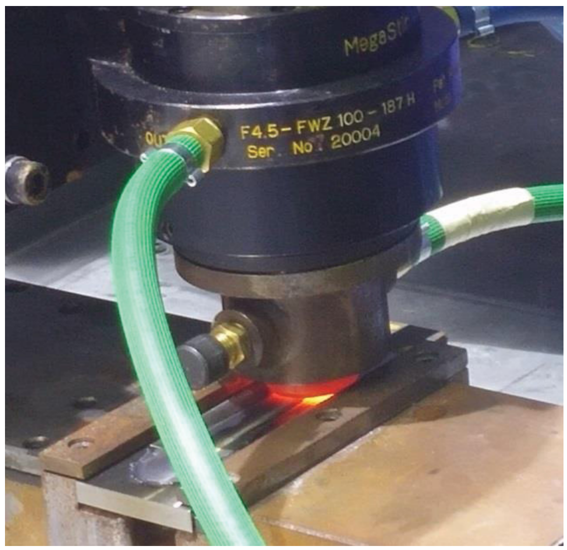

Figure 3: Friction Stir Weld in the Hot Cell Welding Cubicle at ORNL's 7930

Multiple FSW tools were evaluated along with some limited variations in weld process variables (*Table 1*) to identify parameters the yielded the best system performance.

Table 1: FSW Parameters for Cold Testing

Weld No.	Tool	Weld Z Path Travel	RPM	IPM
001	1	0.329 inch	400	2
002	1	0.329 inch	400	2
003	1	0.339 inch	400	2
004	2	0.329 inch	400	2
005	2	0.485 inch	400	2

Overall, the system performed very well from both mechanical and controls perspectives. Figure 4 displays friction stir Weld No. 5 from the cold testing. The PLC control system executed all automated functions as anticipated, and the result was a series of continuous friction stir welds that served to validate system functionality and form a baseline of weld performance that can be further refined through continued process development in anticipation of welding irradiated materials.

Figure 4: Completed FSW Specimen No. 5 from Cold Testing for System Performance Validation

III. Summary

The development of advanced welding process capable of repairing highly irradiated materials represents a significant advancement in the management of materials degradation and the extension of operating lifetimes of existing nuclear power plants. The dedicated one of a kind welding hot cell at ORNL will serve as vital asset to researchers in the development and testing of these processes. The welding cubicle has been successfully integrated into ORNL's Building 7930, which included a significant installation effort with respect to accommodation of the supporting equipment, transferring the cubicle to the hot cell, and making system connections to enable full functionality of the FSW system. Welding activities have been evaluated to determine the safety protocols necessary for start-up of operations. In particular, the laser hazard analysis was completed, and it was determined that a Facility Readiness Assessment is not required for start-up of welding R&D activities on irradiated materials. Review of the Safety Basis Supplement that covers this activity is underway. Furthermore, the full functionality of the FSW system was demonstrated with weld trials performed on unirradiated representative stainless steel material. System performance was validated, with mechanical and control systems performing as expected and with multiple continuous friction stir welds produced that will serve as a baseline of weld performance going forward, as preparations continue for welding irradiated materials.